**EQUILIBRATION OF PYROXENES IN TYPE 4-6 LL CHONDRITES.** R. H. Jones, Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, USA. rjones@unm.edu.

Introduction. The metamorphic sequence, petrologic types 3-6, exhibited by ordinary chondrites (OCs) is characterized by progressive equilibration of silicate mineral compositions. Equilibration of olivine occurs within petrologic type 3, whereas pyroxene compositions in OCs up to type 6 remain unequilibrated [1]. I have begun a study of pyroxenes in specific environments in type 4-6 OCs in order to track compositional changes that occur during thermal metamorphism. This is intended to provide some insight into the mechanism of diffusional exchange of material throughout the chondrite, and will hopefully allow an assessment of the approach to equilibrium as metamorphism proceeds.

Samples. A suite of LL chondrites was examined, including Bo Xian (LL4), Sevilla (LL4), Tuxtuac (LL5), and Beeler (LL6). Pyroxene in Bo Xian is very unequilibrated compared with pyroxene in Sevilla. Compositions of pyroxenes in these chondrites can be compared with previous studies of Semarkona (LL3.0) [2,3]. Pyroxenes from type IAB and type IIAB chondrules were selected: these are porphyritic, pyroxene- and olivine-bearing types of chondrules, which are FeO-poor (type I) and FeO-rich (type II) in unequilibrated chondrites. Type IAB chondrules are characterized by a poikilitic texture of small olivine grains in pyroxene phenocrysts. In type IIAB chondrules, poikilitic textures are less common, olivine and pyroxene phenocrysts are more similar in size, and olivine tends to show hopper or skeletal morphologies. Chondrules or chondrule remnants with these textures were identified in the type 4-6 chondrites. In all these chondrules, pyroxene phenocrysts are low-Ca pyroxene, which is usually clinoenstatite in Semarkona, becoming progressively inverted to orthoenstatite with increasing petrologic type. In both chondrule types, Ca-rich pyroxene, either augite (Wo<45) or diopside (Wo>45), commonly occurs as rims on low-Ca pyroxene phenocrysts in Semarkona. This association is preserved up to the type 6 chondrites, although in types 5 and 6 the Ca-rich pyroxene rims have undergone extensive resorption into the surrounding mesostasis. This study reports electron microprobe analyses of two-pyroxene pairs in this intimate association throughout the metamorphic sequence.

Results. Pyroxene compositions are plotted in pyroxene quadrilaterals in Fig. 1. For the type IAB chondrules, Fs contents increase from Fs<10 in Semarkona and Bo Xian to Fs~25 for low-Ca pyroxenes and Fs~10 for Ca-rich pyroxenes in Sevilla, Tuxtuac, and Beeler. For type IIAB chondrules in Sevilla, Fs contents approach similar values to those in the type IAB chondrules, as a result of FeO gain in low-Ca pyroxene and FeO loss in Ca-rich pyroxene. The Wo content of low-Ca pyroxenes in both chondrule types is significantly higher in Sevilla, Tuxtuac, and Beeler (Wo~1.5) than in Semarkona and Bo Xian (mostly Wo<1). Wo contents in Beeler are lower than expected for a type 6 chondrite (>1.6% [4]). Ca-rich pyroxenes in type IAB chondrules in Sevilla, Tuxtuac, and Beeler are Wo~45, and show a much smaller range than compositions in Semarkona and Bo Xian. In comparison, Ca-rich pyroxenes from type IIAB chondrules in Sevilla show considerable variation in Wo content.

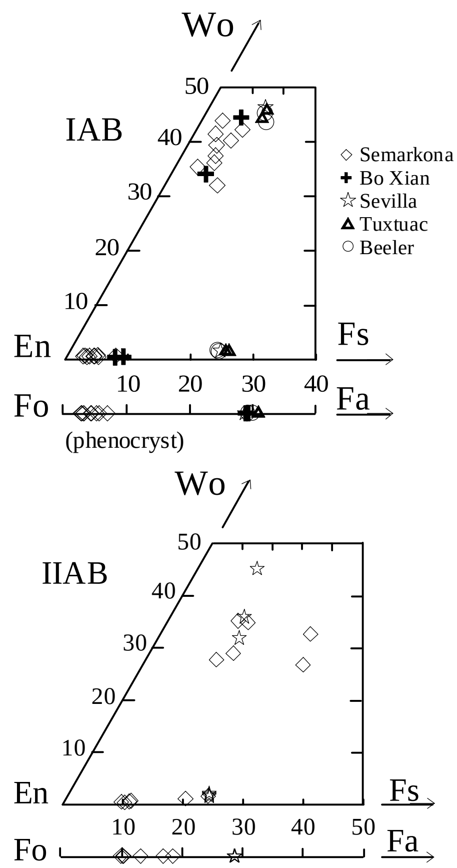


Fig. 1. Pyroxene compositions in type IAB and type IIAB chondrules in type 3-6 LL chondrites. Each point represents the mean of 6-10 analyses in individual chondrules.

Application of the Lindsley two-pyroxene geothermometer [5] to the pyroxenes in type IAB chondrules gives temperatures of 800 °C for low-Ca pyroxene in Sevilla, Tuxtuac, and Beeler. However, temperatures for Ca-rich pyroxenes increase from about 600°C for Sevilla to 650-800°C for Beeler. This lack of equilibrium both between the two pyroxenes in individual chondrules and between different chondrules is consistent with the observations of [1].

Minor element contents of pyroxenes in Semarkona generally show significant variations between chondrules. For most elements, there are distinct differences between the ranges in type IAB and type IIAB chondrules. During metamorphism, differences between chondrules are erased, and compositions become progressively more equilibrated. Figure 2 shows $Al_2O_3$ contents of the pyroxenes. A range of 0-1 wt% in low-Ca pyroxene appears to have equilibrated to ~0.1 wt% $Al_2O_3$ in Tuxtuac and Beeler. However, $Al_2O_3$ contents of Ca-rich pyroxene do not appear to be equilibrated in Sevilla or Tuxtuac. Since there is a wide range in $Al_2O_3$ for these pyroxenes in Semarkona and Bo Xian, 0-12 wt%, perhaps it is not surprising that Ca-rich pyroxenes appear to take longer to equilibrate than low-Ca pyroxenes.

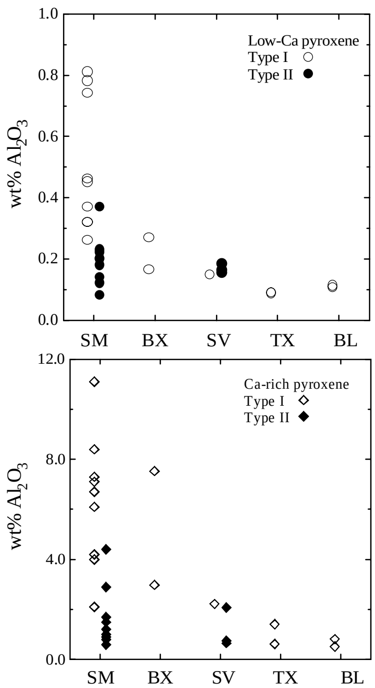


Fig. 2. $Al_2O_3$ contents of pyroxenes in type 3-6 LL chondrites, arranged in order of increasing metamorphic grade.

In contrast to $Al_2O_3$, MnO appears to equilibrate relatively rapidly in both types of pyroxene (Fig. 3). For low-Ca-pyroxene, MnO contents are higher in Sevilla, Tuxtuac and Beeler than in Semarkona and Bo Xian, and are equilibrated at about 0.4 wt% MnO. Ca-rich pyroxene loses MnO during metamorphism and equilibrated values are around 0.2 wt% MnO.

$Cr_2O_3$ contents of low-Ca pyroxenes are equilibrated at low values in low-Ca pyroxenes in Sevilla, Tuxtuac, and Beeler, but are very heterogeneous in Ca-rich pyroxene even in Beeler (Fig. 4). $TiO_2$ behaves in a similar way to $Cr_2O_3$ and is heterogeneous in Ca-rich pyroxenes in Beeler.

As expected, olivine compositions in the same chondrules are homogeneous in all the type 4-6 chondrites studied. Olivine equilibrates to a composition $Fa_{29}$, CaO<0.04wt%, MnO~0.45wt%, $Cr_2O_3$<0.1 wt%.

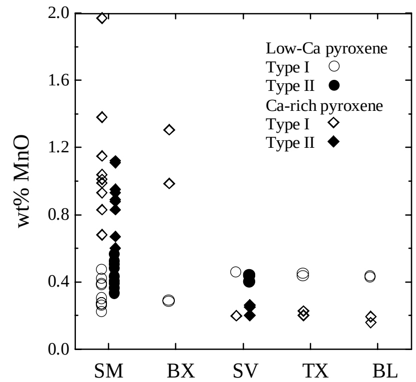


Fig. 3. MnO contents of pyroxenes.

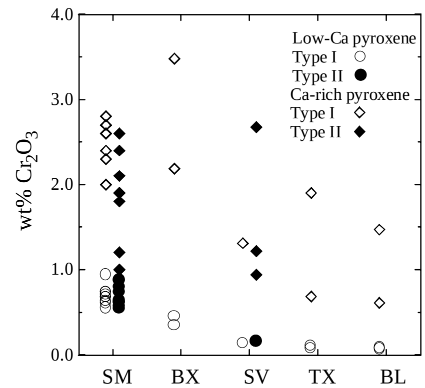


Fig. 4. $Cr_2O_3$ contents of pyroxenes.

Conclusions. Based on these preliminary data, it appears that low-Ca pyroxene appears to equilibrate more rapidly than Ca-rich pyroxene during metamorphism. Low-Ca pyroxenes in Sevilla (LL4), Tuxtuac (LL5) and Beeler (LL6) are quite homogeneous and show no significant changes in composition with petrologic type above type 4. In contrast, Ca-rich pyroxenes are heterogeneous even in type 6. This is consistent with much greater heterogeneity and stronger zoning of Ca-rich pyroxenes than low-Ca pyroxenes in Semarkona (LL3.0). However, heterogeneity of minor element compositions in Ca-rich pyroxenes from chondrites of higher petrologic type may also be the result of ongoing reactions with other phases in the surrounding environment.

References. [1] McSween H.Y.Jr. and Patchen A.D. (1989) Meteoritics 24, 219-226. [2] Jones R.H. (1994) GCA 58, 5325-5340. [3] Jones R.H. (1996) GCA 60, 3115-3138. [4] Scott, E.R.D. et al. (1986), JGR 91, E115-E123. [5] Lindsley D.H. (1983) Am. Min. 68, 477-493.

Acknowledgments. This research was supported by NASA grant NAGW 3347 to J.J. Papike (P.I.)